# SAGE-GROUSE WINTER HABITAT SELECTION AND ENERGY DEVELOPMENT IN THE POWDER RIVER BASIN: COMPLETION REPORT

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## EXECUTIVE SUMMARY

The recent surge in coal-bed natural gas (CBNG) development has resulted in rapid and large-scale changes to sagebrush habitats in the Powder River Basin (PRB) of Montana and Wyoming without a complete understanding of its potential impacts to wildlife populations. As part of a larger study investigating the impacts of CBNG on greater sage-grouse (*Centrocercus urophasianus*), we conducted research on winter habitat use in the PRB to 1) identify landscape features that influence sage-grouse habitat selection, 2) to assess appropriate scale(s) at which selection occurs, and 3) to develop a conservation planning tool by spatially depicting winter habitat quality in a GIS. Vegetation and topographic variables drove the model which predicted an independent data set of winter sage-grouse locations ($R^2 = 0.961$). After controlling for habitat quality, the addition of a variable quantifying the average number of wells/km$^2$ within 1000 m of used and available points indicated that sage-grouse avoid CBNG development in otherwise suitable habitat. An Akaike weight of 0.998 showed that the model with habitat and energy development variables included has complete support as the best model to explain the information in the data set. Knowledge that sage-grouse avoid energy development in breeding (Naugle et al. 2006) and wintering seasons (this report) shows that conservation strategies to date to protect the species have been largely ineffective. An effective conservation strategy is one that limits the cumulative impact of disturbances across a landscape at all times of the year. There is still time to develop and

implement an effective conservation strategy in the PRB because some areas of high quality winter habitat are still undeveloped. Winter habitat is limited for birds along the border of Montana and Wyoming. Movements of radio-marked birds indicate that this non-migratory population remains in small parcels of suitable habitat to breed, raise broods, and spend the winter. The most suitable winter habitat in Montana and northern Wyoming encompasses only 13% of total land area and has already been impacted by surface mining activities. Expansion of CBNG development threatens to extirpate birds from otherwise suitable habitats and further isolate remaining populations. Risk of complete loss of this population is high if plans proceed to develop the entire northern study area because their non-migratory status and behavioral avoidance of CBNG will leave these birds with no other options. Comparatively more undeveloped winter habitat exists further south in Wyoming (south and east of the town of Buffalo) than along the border of Montana and Wyoming. Large pieces of undeveloped habitat near Buffalo provide winter habitat for a migratory population that nest up to 28 km to the north where winter habitat is poor. Some of these same good wintering areas also contain resident populations of nesting birds that distribute themselves around active leks with >20 males in attendance. Spatially-explicit planning tools, when coupled with knowledge of bird movements and active lek locations provide a biological basis for decision-makers to formulate an effective conservation strategy for sage-grouse. The next step for stakeholders is to formulate the strategy, evaluate alternatives and initiate implementation.

## INTRODUCTION

Little emphasis has been placed on researching winter habitat selection for greater sage-grouse (*Centrocercus urophasianus*) compared to breeding-season studies. Winter habitat was not previously thought to limit sage-grouse populations because previous studies of annual and breeding season survival have assumed high rates of winter survival (Robertson 1991, Wik 2002, Hausleitner 2003, Moynahan et al. 2006, Zablan et al. 2003, reviewed in Connelly et al. 2004). But sage-grouse often move long distances to suitable winter habitat, and wintering areas support the highest bird densities of any seasonal habitat. For example, Beck (1977) found that 80% of use sites occurred in less than 7% of the total area of sagebrush available in Colorado. The relationship between sagebrush and sage-grouse is arguably the closest during winter when birds switch from a diet of insects, forbs and sagebrush to one composed of >96% sagebrush (Remington and Braun 1985, Welch et al. 1991, Connelly et al. 2000*a*, Crawford et al. 2004). Heavy snowfall may even further reduce habitat suitability by limiting the abundance of sagebrush above the snow (Connelly et al. 2000*a*, Connelly et al. 20004, Hupp and Braun 1989). Thus, impacts to wintering habitat may have disproportionate effects on regional population size and persistence.

Previous winter habitat studies have investigated the importance of micro-site vegetation features such as sagebrush height, canopy cover, or crude protein levels (e.g. Eng and Schladweiler 1972, Beck 1977, Connelly et al. 2000*a*, Crawford et al. 2004, Sauls 2006). In winter, sage-grouse use areas with moderate to dense sagebrush (Eng and Schladweiler 1972, Homer et al. 1993, Connelly et al. 2000*a*) and typically prefer areas with gentle slopes <10% (Beck 1977, Hupp and Braun 1989), and south or west facing aspects (Hupp and Braun 1989). While these relationships further our understanding, previous studies have not conveyed information about winter habitat quality at a spatial scale that can be used to prioritize landscapes for conservation. Only one past study used satellite imagery to quantify habitat selection for sage-grouse on a broad scale; this study was able to accurately predict winter locations from an independent dataset well using log-linear modeling (Homer et al. 1993). Modeling sage-grouse winter habitat selection from high-resolution satellite imagery using resource selection functions (RSF) offers the ability to rank specific areas by their relative probability of use. Resulting probability layers can then be mapped in a Geographic Information System (GIS) to prioritize landscapes for conservation. Further, these models allow cross-validation (Boyce et al. 2002, Johnson et al. 2006) and testing of independent datasets to ensure that habitat selection models are robust. Lastly, the relative influence of variables can be assessed in a competing-model framework (Burnham and Andersen 2002) to determine their role in habitat selection.

Recently, coal-bed natural gas (CBNG) development has caused rapid, large-scale changes to sagebrush habitats in the Powder River Basin (PRB) of Montana and Wyoming. As part of a larger study investigating the potential impacts of CBNG on sage-grouse populations, we initiated research into sage-grouse wintering habitat use in the PRB. The objectives of our study were to: 1) generate a robust model for sage-grouse winter habitat selection, 2) determine the appropriate scale of habitat selection, 3) spatially depict winter habitat suitability in a GIS to quantify the distribution and size of areas with a high probability of use, and 4) assess the effect of CBNG development on winter habitat selection after controlling for habitat quality.

## METHODS

### STUDY AREA

Our 1,570,868 ha (3,861,549 ac) study area corresponded to the extent of SPOT-5 satellite imagery that was classified to land cover in the PRB. Sagebrush-steppe habitat in the PRB is dominated by Wyoming big sagebrush (*A. tridentata wyomingensis*) and plains silver sagebrush (*A. cana cana*) intermixed with native and non-native grasses such as bluebunch wheatgrass (*Pseudoroegneria spicata*), western wheatgrass (*Agropyron smithii*), prairie junegrass (*Koeleria macrantha*), blue grama (*Bouteloua gracilis*), Japanese brome (*Bromus japonicus*), cheatgrass (*Bromus tectorum*) and crested wheatgrass (*Agropyron cristatum*). Rocky mountain juniper (*Juniperus scopulorum*) and ponderosa pine (*Pinus ponderosa*) were intermixed in draws and formed forests across the extreme northern extent of the study area. Conifers were largely absent from the southern half of our study area. Land use is dominated by cattle ranching with limited irrigated agriculture. The PRB is cold and dry in January with average temperatures of

-6°C and 16.3 cm of snowfall. Conditions were almost identical to historical averages in the winters of 2004 and 2005. In January 2006, the field season was mild, with temperatures 6.5°C above normal and snowfall 15 cm below average.

Energy development in the form of CBNG is of concern because other sources of anthropogenic change already make habitat loss and degradation the most important factor leading to isolation, reduction, and extirpation of sage-grouse populations (Braun 1998, Connelly et al. 2000*a*,*b*; Aldridge and Brigham 2002, Knick et al. 2003). Previously widespread, the species has been extirpated from ~50% of its original range, with an estimated range-wide population decline of 45–80% and local declines of 17–92% (Connelly and Braun 1997, Braun 1998, Connelly et al. 2000*a*, Aldridge and Brigham 2003). Recent analyses (D. E. Naugle, unpublished data) show that landscapes with CBNG development have twice the length of roads (3.3 – 4.1 km per $km^2$) and 2-3 times as many power lines (0.6 – 0.8 km per $km^2$) as similar landscapes without energy development. Further analyses show that 70-80% of all sagebrush is within 200 m of an anthropogenic feature in landscapes with CBNG development (D. E. Naugle, unpublished data). The BLM in Wyoming allowed full-scale CBNG several years ago in the PRB with authorization of a plan to drill 51,000 wells. There is the potential for an additional 15,000 wells to be drilled in Montana. An analysis of the current distribution and pace of development shows that the PRB is likely to be drilled at 32.4 ha (80 ac) spacing in less than 20 years (D. E. Naugle, unpublished data), leaving sage-grouse no place else to go.

## SAGE-GROUSE USE LOCATIONS

Sage-grouse were captured from leks in three main study areas: 1) North; 30 km north and 40 km northeast of Sheridan, Wyoming, 2) Spotted Horse; in direct proximity to the town of Spotted Horse, Wyoming and 3) South; 20 km east and 37 km southeast of Buffalo, Wyoming. Sage-grouse were captured by rocket-netting (Giesen et al. 1982) and spotlighting (Wakkinen et al. 1992). We aged and sexed grouse and fitted females with a 21.6 g necklace style radio collar (model A4060 ATS, Isanti, Minnesota). Birds were relocated from the air during three flights between 2-25 January 2005 (*n* = 292 locations on 106 individuals) and 24 December 2005 - 1 February 2006 (*n* = 241 locations on 94 individuals).

A 95% error polygon was estimated by relocating a transmitter at a known location from the air 40 times in a blind trial. We then calculated a bivariate normal home range estimator (Jennrich and Turner 1969) using these relocations to quantify the spatial error in our data (78.2 m). The smallest spatial scale modeled for winter sage-grouse habitat selection was 100 m to ensure that our inference was not confounded by spatial error.

## AVAILABLE POINTS

We used movements of our radio-marked female sage-grouse to define available wintering areas. Random available points fell within polygons that depicted the shortest distance from capture leks that contained all winter locations of radio-marked sage-grouse (28 km in north and south study areas, 23 km at site near Spotted Horse). We generated random available points using a uniform distribution (Beyer 2004). To ensure we had a representative sample of available habitats we selected twice the number of random points for each known sage-grouse location. We weighted random points spatially and temporally with sage-grouse use locations because distributions of bird locations were not equal across study areas, and to account for increases in CBNG development between the winters of 2005 and 2006.

## HABITAT CLASSIFICATION

We acquired SPOT-5 satellite imagery of the study area from Terra Image USA. Images were acquired for the northern area in August 2003 and for the southern area in August 2004. Images were acquired in two pieces because the project expanded in 2004 to encompass a much larger geographic area. We ortho-rectified SPOT-5 imagery to existing digital ortho-quads of the study area. The SPOT-5 panchromatic and multi-spectral images were mosaiced into a single panchromatic, multi-spectral file. We then used the panchromatic 5 m pixel image to perform pan-sharpening to reduce the multi-spectral image pixel size from 10 m to 5 m, greatly increasing the resolution of our analysis. eCognition™ 4.0 software was used to segment the image to produce regions representing spectrally discrete ground features. Segments were exported into Arc/Info software to create a polygon database. We then collected field training samples ($n$ = 7,092) to provide raw data for creating unique habitat cover classes. Overall classification accuracy was 78.5% for grass, riparian, sagebrush, conifer, and bare ground cover classes. Urban areas and strip mines were masked from analyses.

## HABITAT AND ENERGY DEVELOPMENT VARIABLES

We calculated the percent of total area covered each of the 5 cover classes within a 100, 400, and 1,000 m rectangular buffer for each pixel in the landscape. Cover classes that were correlated ($r > 0.5$) were not allowed in the same model. We estimated elevation values from 30-m resolution Digital Elevation Models (DEM). We then processed the DEM using Spatial Analyst from Environmental Systems Research Institute (ESRI) to estimate slope and aspect for every pixel in the landscape. Lastly, we calculated a roughness index defined as the standard deviation of the DEM elevation based upon a 100, 400, and 1,000 m buffer for each scale.

Sagebrush was re-sampled to a 30 m pixel size because time required to process a 1000 m buffer for 6.2 million pixels exceeded our computational capacity. Sagebrush resampled well and little information was lost when evaluating the 30-m resampled sagebrush layer vs. the original 5-m resolution sagebrush layer (correlation coefficient = 0.934). Conifer resampled poorly (correlation coefficient = 0.793) so this variable was kept at the original 5-m pixel size for a 400 m buffer.

We mapped all aspects of CBNG infrastructure within a sample of areas and showed in a Principal Components Analysis that wells are a good ecological indicator that portrays all other facets of the energy footprint (i.e., associated roads, CBNG ponds, power lines, compressor stations, pipelines; D. E. Naugle, unpublished data). This is important as CBNG wells are the only segment of the energy footprint that is mapped across the entire PRB. Thus, we used the density of CBNG wells as a measure of the extent of CBNG development for comparison with grouse winter use locations. We modeled well density in 100, 400, 1000-m buffers and recorded the average number of wells/km$^2$ using the point density command in Spatial Analyst by ESRI.

## STATISICAL MODELING AND MODEL SELECTION

Logistic regression was used in a use/available design to generate beta coefficients for RSF models (Manly 2002, Boyce 2002, Johnson et al. 2006). The resulting RSF model had the form:

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3) \quad (1)$$

We categorized habitat variables into 3 classes of models: vegetation, topography, and energy development. We used Information-Theoretic methods (Burnham and Andersen 2002) to select the most parsimonious model for habitat selection within each class and amongst all classes combined. Since individual variables represented at varying scales are correlated, we choose the scale that best represented sage-grouse habitat selection and only that scale for each variable was allowed to compete with other variables. Once the best models within model classes were selected, we then allowed model classes to compete to see if the additional information increased model fit. Correlated variables were not allowed in the same model at any level of model selection. If variables were correlated we chose the variable that had the most biological meaning to known wintering sage-grouse habitat characteristics.

To create a spatially-explicit habitat model we applied beta coefficients from Equation 1 to GIS layers in Spatial Analyst by ESRI. The output was a new GIS layer that represents the RSF values for each individual 25-$m^2$ pixel for the entire landscape. We categorized RSF values into 8 ordinal quartile bins representing progressively selected habitats. We validated this model with an independent test data set collected in January 2004 in the northern study area. This data set had 37 new locations that were not used to build the model, of which 46% were from marked birds that were not monitored in subsequent years. We regressed the observed proportion of the test data set in each RSF bin against the expected proportion of use from the original RSF model to evaluate model fit (Johnson et al. 2006). A good model fit should have a high $R^2$ value, a constant not different from 0, and a slope not different from one (Johnson et al. 2006).

After controlling for habitat quality, we evaluated whether sage-grouse avoid energy development in winter. We used AIC values to determine if the addition of the number of CBNG wells/$km^2$ to the habitat model explained more information than habitat alone. If the energy variable was included in the most parsimonious model we then looked at the resulting beta coefficient to determine if grouse avoid energy development.

**RESULTS**

Vegetation and topographic variables were each important to winter habitat selection, but model fit increased when model classes were combined (Table 1). Scale at which vegetation and topographic variables were quantified strongly influenced model fit. Of the five vegetation variables quantified only sagebrush at 1000 m scale and conifer at 400 m were included in the vegetation model. The difference in the abundance of sagebrush at used and available sites was greatest at the 1000 m scale, suggesting that sage-grouse selected large intact expanses of sagebrush. Sage-grouse also showed a strong avoidance of conifer habitat at 400 m, a relationship that would have been less discernible at broader spatial scales. Our roughness index out-competed other topographic variables including as slope, aspect, and elevation. Sage-grouse selected for less rugged landscapes at a 400 m scale in winter.

This model (Table 2) predicted an independent data set of winter locations extremely well. The regression of the observed proportion of the test data set to the expected proportions in each RSF category was $R^2 = 0.961$. Slope of the observed vs. expected was 0.993 and the 95% CI included 1.0 (Figure 1). The constant did not differ from zero.

After controlling for habitat quality, sage-grouse avoided CBNG development that was located in otherwise suitable habitat (Table 2). The addition of the average number of wells/km$^2$ within a 1000 m buffer improved model fit by >12 AIC points (Table 1). An Akaike weight of 0.998 indicated that the model with habitat and energy variables has almost complete support as the best model to explain the information in the data set.

The top 3 RSF classes accounted for 83.1% of the 532 locations used to create the RSF model and 83.8% of locations in the test data set. Since quartile methods were used to break all 5-m$^2$ pixels in to equal bin widths, all classes have an approximately equal area in the landscape (Figure 2). However, when this is represented spatially it becomes apparent that high quality wintering habitat (RSF bins 6-8) is limited along the border of Montana and Wyoming (Figure 3). Of the 328,567 ha of potential habitat in Montana, only 13.4% is in the highest quality sagebrush habitat (i.e., RSF bins 6-8) (Figure 4). And because sage-grouse are selecting for less rugged landscapes, most of the high quality habitat also is on flat land that is under private ownership. Of the top 3 classes, the BLM only controls 0.9% of the total surface area in Montana. The BLM does control mineral development via sub-surface ownership on 55% of the best winter habitat in Montana (Figure 4).

## DISCUSSION

Our landscape approach to modeling worked well for predicting the habitat needs of sage-grouse in winter. Ideally, fine-scale vegetation measures (Eng and Schladweiler 1972, Beck 1977, Connelly et al. 2000*a*, Crawford et al. 2004, Sauls 2006) should compete in an AIC framework against landscape-scale variables to assess which habitat attributes are most important. Funding limitations did not allow us to collect fine-scale measures in this study. But given the high predictive capability of our model, it would be interesting to see if the addition of fine-scale measurements would increase model fit.

Selection by sage-grouse for sagebrush habitats in less rugged landscapes is not surprising. But the strength of the relationship at a 1000 m scale shows that the abundance of sagebrush over a broad area is an important predictor of its use by sage-grouse in winter. Sage-grouse avoided coniferous habitats at a finer 400 m scale, a relationship that would have been less discernible at broader spatial scales. Our roughness index out-competed other topographic variables, indicating that sage-grouse selected less rugged landscapes in winter. Past research suggests that elevational migration is an important aspect in the wintering biology of sage-grouse (Patterson 1952, as summarized by Connelly et al. 2004). But elevational migration may not be necessary in the Power River Basin where average elevation is 1,300 m.

An inherent limitation in any habitat study is that the inference is limited to the conditions in which models were built. This study was conducted during mild to average winter conditions. Extreme winter conditions with deep snow pack and low temperatures could move birds into more rugged landscapes as they search for sagebrush above the snow and for protection from high winds (Connelly et al. 2004). We need location data from radio-marked birds during a harsh winter in the PRB to evaluate whether we have defined suitable habitat broadly enough.

Vegetation and topographic variables drove the model as evidenced by large decreases in AIC values. Validation of the habitat model subsequently enabled us to show that sage-grouse avoid energy development in winter. We do not assume a cause and effect relationship here because there is a chance that none of our radio-marked birds previously wintered in areas that are now developed (Figure 5). To rule out this possibility, some of the best remaining winter habitat where we have marked birds would need to be fully developed. We do not advocate for this design, but rather simply point out that with the rapid pace and distribution of development, we are unlikely to clear up this uncertainty before the best remaining winter habitats are fully developed.

Recent research has shown that sage-grouse either avoid energy development during the breeding season (Holloran 2005, Naugle et al. 2006) or experience rates of mortality that result in extirpation (Holloran 2005). Avoidance is typically detrimental to populations because individuals are forced into sub-optimal habitats where vital rates decline (i.e., survival and reproduction), which in turn negatively influences population growth rate, size, and persistence, and generally leaves populations with little capacity to respond to new stressors (e.g., West Nile virus). New knowledge that sage-grouse also avoid energy development during winter shows that conservation strategies to date to protect this species have been largely ineffective. Current "Best Management Practices" that place timing stipulations or limit surface occupancy next to leks still result in a human footprint that far exceeds the tolerance limits of sage-grouse. We cannot write a prescription for development for each piece of the landscape because the exact mechanisms for each source of disturbance in a gas field that results in avoidance and/or increased mortality are not known. Rather, effective conservation strategies will be those that limit the cumulative impact of disturbances at all times of the year. Size of a functional conservation area will need to be large because sage-grouse are a landscape species that require contiguous tracts of undisturbed habitat that meet all their seasonal life requisites. Holloran et al. (2005) found that nest distributions were spatially related to lek location, and that a 5-km buffer encompassed just 64% of nests. This marks a shift in our understanding of the size of area necessary to maintain a viable sage-grouse population. Thus, land managers are encouraged to think in terms of "numerous square miles" of suitable habitat rather than individual parcels of land or even an individual square mile of habitat.

## MANAGEMENT IMPLICATIONS

There is still time to develop and implement a conservation strategy in the PRB because areas of high quality winter habitat for sage-grouse are undeveloped. And when winter habitat requirements are depicted reliably in a GIS, the resulting maps are powerful tools for prioritizing conservation activities. Winter habitat is limited for birds along the border of Montana and Wyoming. Movements of radio-marked birds indicate that this population does not migrate. Instead, birds remain in small parcels of suitable habitat to breed, raise broods, and spend the winter. The most suitable winter habitat in Montana (green, orange and red) currently encompasses 13% of total land area and has already been impacted by surface mining activities (Figure 5). Now expansion of CBNG development threatens to extirpate birds from otherwise suitable habitats and further isolate remaining populations. Risk of complete loss of this population is high if plans proceed to develop the entire northern study area because their non-migratory status and behavioral avoidance of CBNG will leave these birds with no other options.

Comparatively more undeveloped winter habitat exists in further south in Wyoming (south and east of the town of Buffalo) than along the border of Montana and Wyoming (Figure 5). The migratory status of this population is known from radio-marked birds. Large pieces of undeveloped habitat to the south and east of the town of Buffalo, Wyoming, provide winter habitat for radio-marked birds that nest as far north as 28 km where winter habitat is poor. Some of these same areas also contain nesting populations of birds that distribute themselves around leks with >20 males each in spring 2005. Our spatially-explicit planning tools, when coupled with knowledge of bird movements and active lek locations provide a biological basis for decision-makers to formulate an effective conservation strategy for sage-grouse. The next step for stakeholders is to formulate the strategy, evaluate alternatives and initiate implementation.

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Table 1. Selection results for a winter sage-grouse habitat model, Powder River Basin, Montana and Wyoming. Each class of model was allowed to compete individually before combining with other model classes to assess model fit.

| Model | Model Class | LL | K | AIC | ΔAIC | $w_i$ |
|---|---|---|---|---|---|---|
| Habitat + CBNG [a] | All | -781.753 | 5 | 1573.506 | 0 | 0.998 |
| Sage [b] + Con [c] + Rough [d] | All Habitat | -788.934 | 4 | 1585.868 | 12.362 | 0.002 |
| Sage + Con | Vegetation | -824.493 | 3 | 1654.986 | 81.48 | 0.000 |
| Rough | Topography | -928.254 | 2 | 1888.056 | 287.002 | 0.000 |
| CBNG | CBNG | -1000.654 | 2 | 2005.308 | 431.802 | 0.000 |

[a] CBNG = mean number of wells/$km^2$ within a 1000 m buffer

[b] Sage = % sagebrush within1000 m buffer

[c] Con = % conifer within 400 m buffer

[d] Rough = roughness of land within a 400 m buffer

Table 2. Logistic regression βeta coefficients (SE) used to develop the best winter habitat and energy avoidance model for sage-grouse winter habitat selection, Powder River Basin, Montana and Wyoming, 2005-06. Coefficients were applied in a GIS to create a raw Resource Selection Function value for each 25m$^2$ pixel in the extent of the classified satellite imagery.

Winter habitat only ΔAIC = 12.4

| | Estimate | SE |
|---|---|---|
| Constant | -1.985 | 0.309 |
| Roughness400m | -0.107 | 0.013 |
| Conifer400m | -0.191 | 0.031 |
| Sage1000m | 0.041 | 0.004 |

Winter habitat and CBNG avoidance ΔAIC = 0

| | Estimate | SE |
|---|---|---|
| Constant | -1.850 | 0.313 |
| Roughness400m | -0.105 | 0.013 |
| Conifer400m | -0.191 | 0.031 |
| Sage1000m | 0.040 | 0.004 |
| Wells1000m | -0.157 | 0.049 |

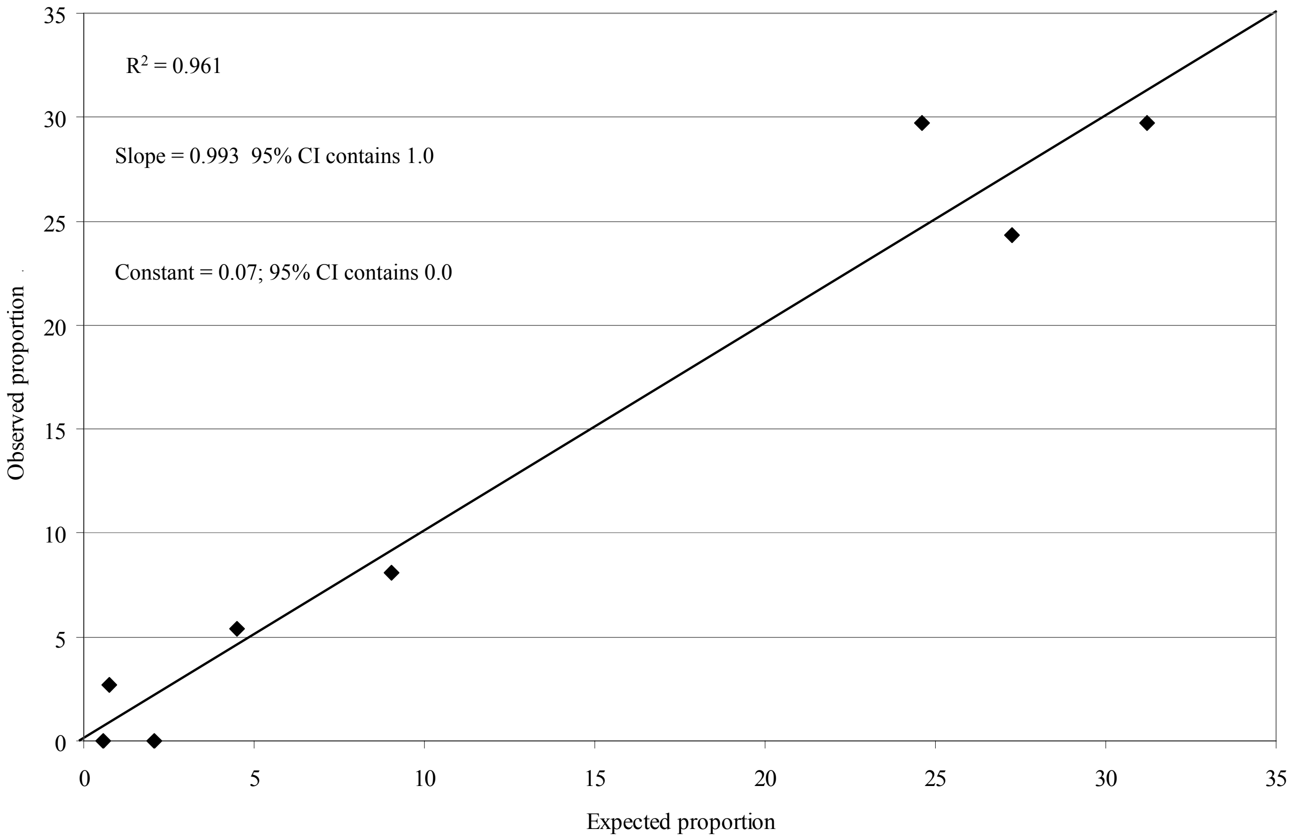


Figure 1. Regression of observed proportion in each RSF bin vs. expected proportions for sage-grouse winter habitat selection for an 8 bin ordinal RSF model using a quartile partitioning method. The test data set is from 37 radio-marked sage-grouse located in January 2004. Straight line represents a perfect slope of 1.0 and a constant of zero.

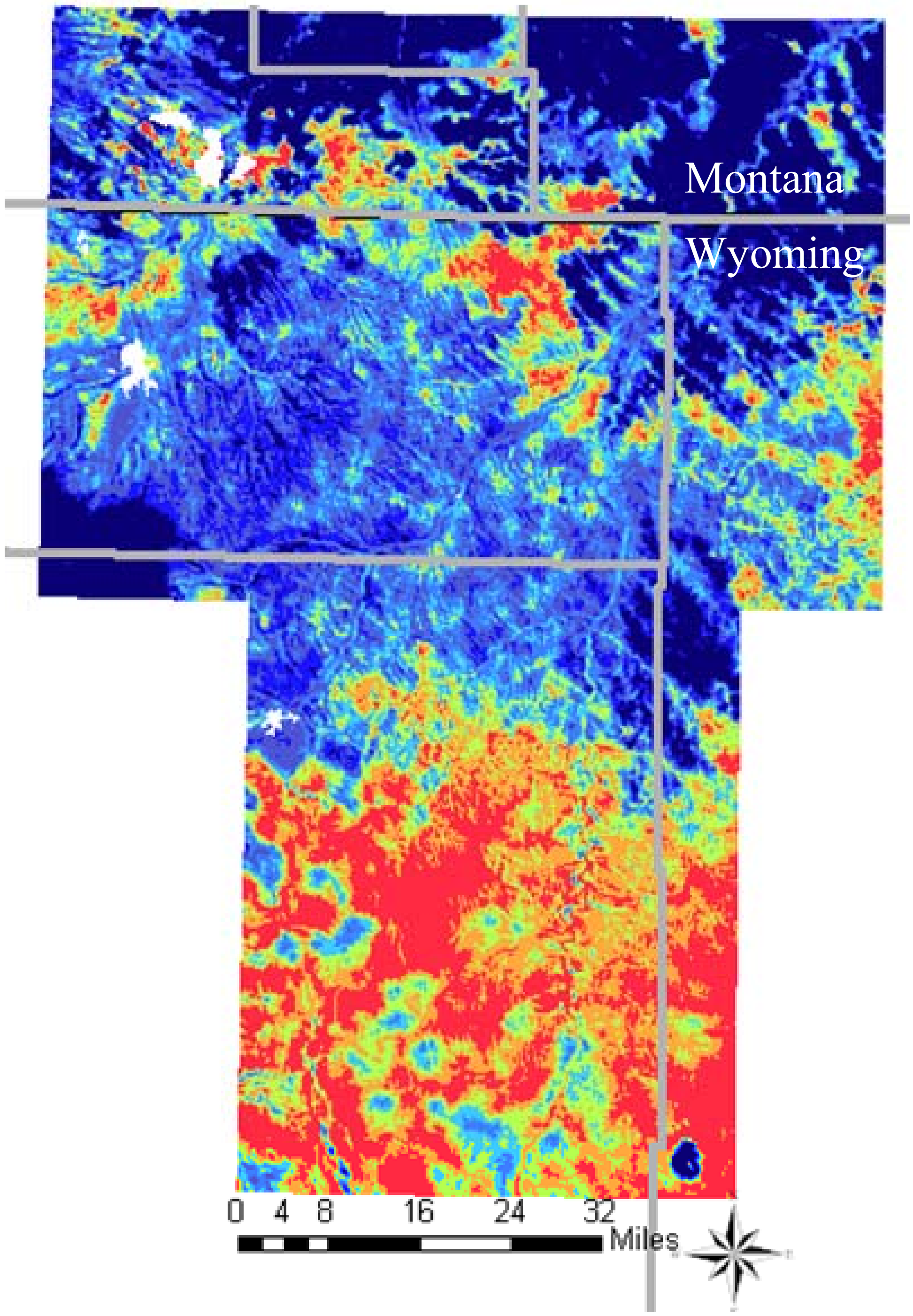


Figure 2. Extent of suitable winter habitat for greater sage-grouse in the Powder River Basin of Montana and Wyoming (1,562,714 ha in area [3,861,549 ac]). A Resource Selection Function (RSF) was developed to code each 25 $m^2$ cell into 1 of 8 ordinal quartile bins. Bins were set to colors to visually depict habitat quality. Warmer colors represent increased habitat suitability for wintering sage-grouse. White areas represent surface mining operations (Decker Coal Company) that were excluded from analyses. Total area shown is 328,567 ha (811,906 ac).

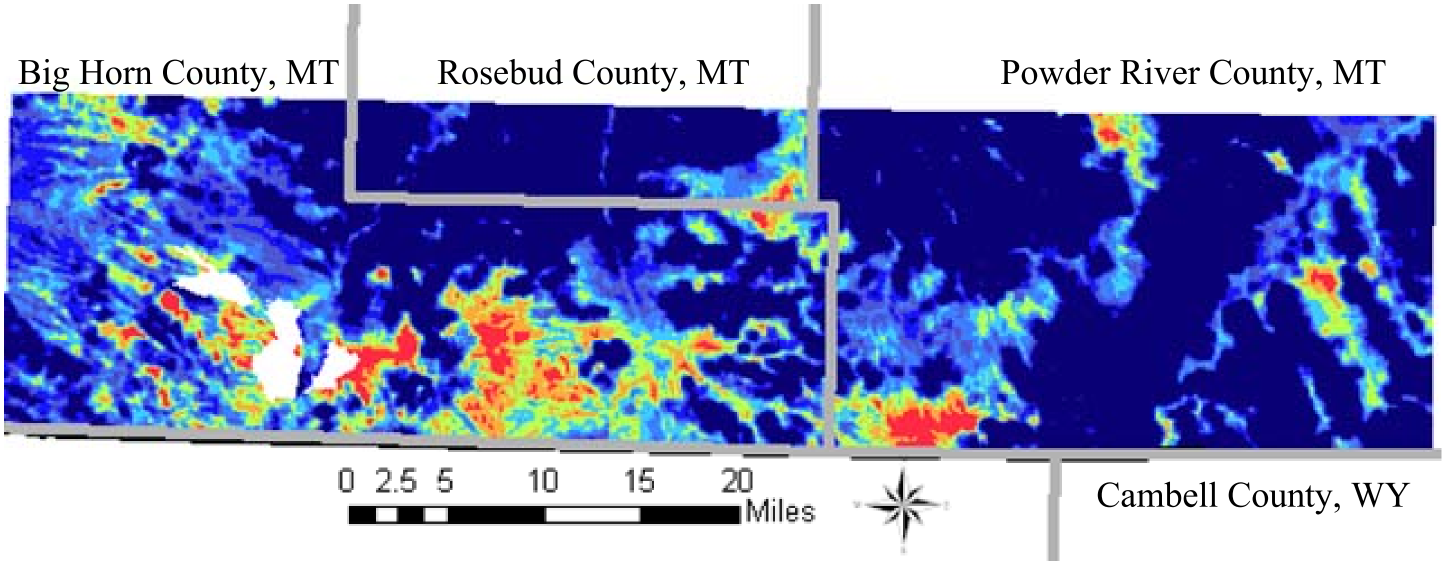


Figure 3. Extent of suitable winter habitat for greater sage-grouse in the Powder River Basin of Montana. A Resource Selection Function (RSF) was developed to code each 25 $m^2$ cell into 1 of 8 ordinal quartile bins. Bins were set to colors to visually depict habitat quality. Warmer colors represent increased habitat suitability for wintering sage-grouse. White areas represent surface mining operations (Decker Coal Company) that were excluded from analyses. Total area shown is 328,567 ha (811,906 ac). The most suitable 3 RSF classes (green, orange and red) encompass 13.4% of total land area and contain 80.4% of the 326 radio-marked sage grouse locations captured in Montana.

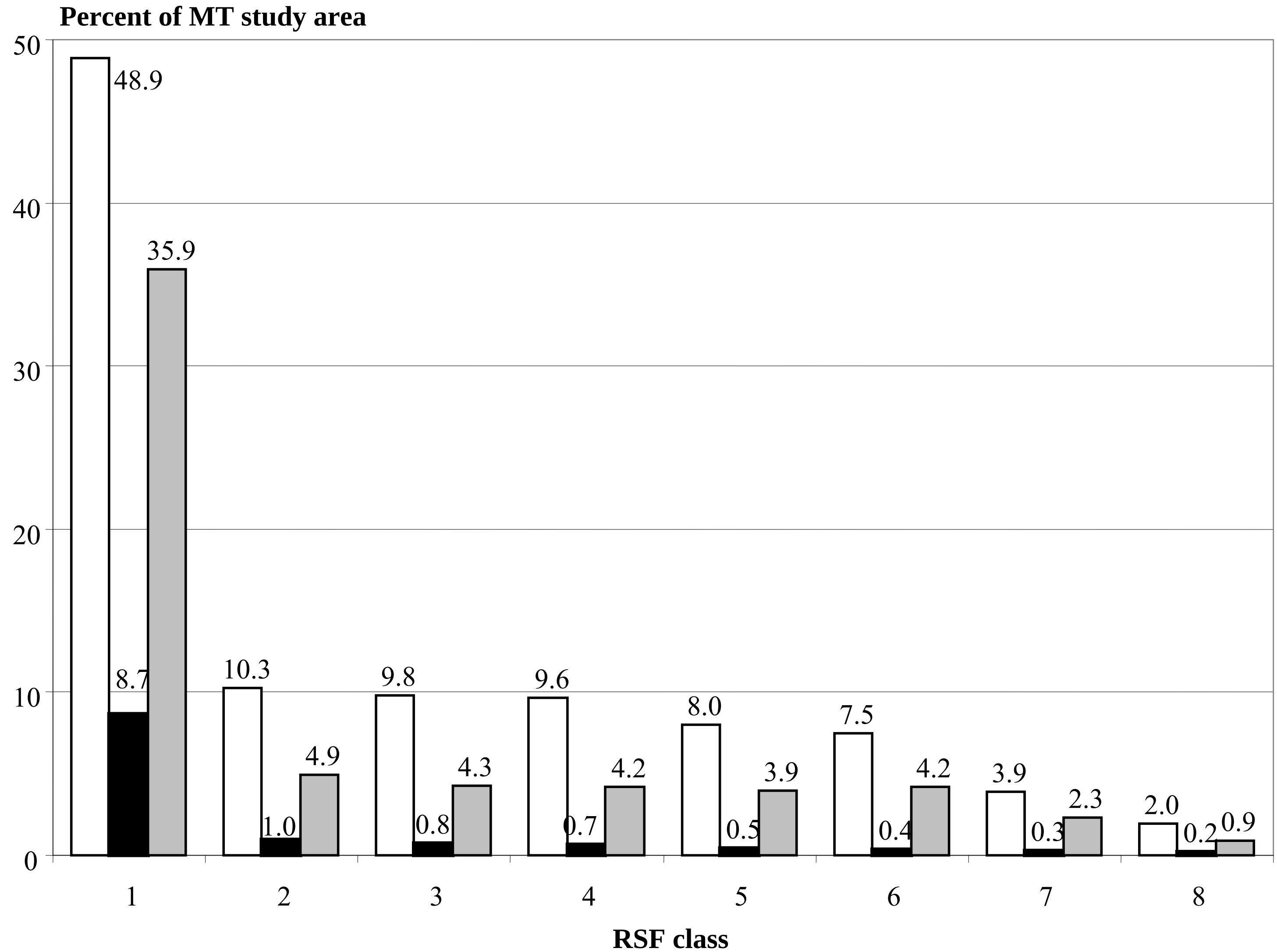


Figure 4. Percent of land area in Figure 3 (328,567 ha [811,906 ac], white bars) within each of 8 classes of habitat suitability as derived from a Resource Selection Function (RSF) for wintering sage-grouse in the Powder River Basin. RSF classes show progressively stronger selection as numbers get larger. The most suitable 3 RSF classes (6-8) encompass 13.4% of land area and contain 80.4% of the 326 radio-marked sage grouse locations captured in Montana. Black bars represent areas within BLM surface ownership[b] (40, 681ha total [100,524 ac]) and grey bars represent the proportion within BLM subsurface ownership [a] (199,084 ha total [491,943 ac]). BLM in Montana owns ~7% of surface and ~55% of sub-surface rights in the best winter habitat (RSF classes 6-8).

[a] Subsurface ownership layer was obtained from Miles City BLM office and should be treated as an approximate area
[b] USFS land was not included in federal land calculations

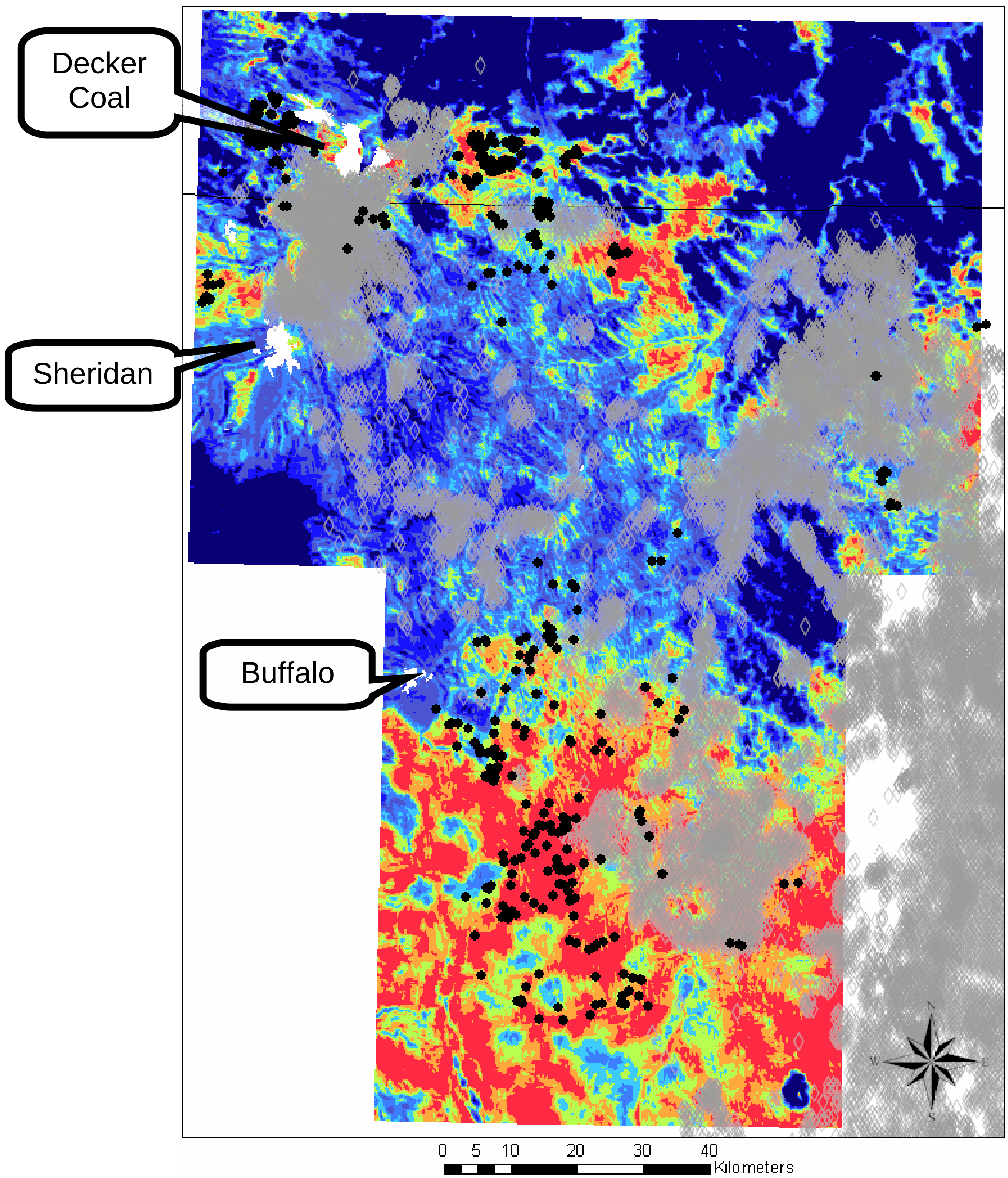


Figure 5. Extent of suitable winter habitat for greater sage-grouse in the Powder River Basin of Montana and Wyoming. Warmer colors represent increased habitat suitability. White areas represent surface mining operations (Decker Coal Company) that were excluded from analyses. Grey symbols represent locations of coal-bed natural gas wells.